Rapsodi

Center for Applied Scientific Computing

Rapid Problem Setup for Diverse Mesh-based Simulations

Technology

The Rapsodi project performs research and develops algorithms aimed at enhancing the ability to rapidly set up computational geometry for large-scale scientific simulations that are based on the solution of partial differential equations in three space dimensions. Current problem setup technology often requires weeks or months to perform this initial setup step, and even incremental changes in geometry can require complete regeneration of the computational mesh. Rapsodi envisions a scenario wherein a complex problem can be set up in a matter of hours and a simulation run overnight, leaving the scientist ready to reformulate the problem specification the next morning and repeat the process. This research project is overcoming the remaining major technical obstacles by focusing a computational science research effort on the critical issues involved.

Figure 1. The geometry for a part of an engine exhaust manifold from the Volvo Car corporation is shown at left as a set of "trimmed NURBS" patches read in from an IGES file. Because of errors in the IGES description, some features are incorrectly represented. The image at right shows the geometry after repair with Rapsodi's interactive RAP tool.

Many of the computational simulation projects at Lawrence Livermore National Laboratory involve the solution of partial differential equations (PDEs) in complex 3D geometric configurations. A significant, recognized area of deficiency in our capability to perform these simulations arises from the inability to rapidly set up and easily modify the computational geometries. The problem setup process consists of all the steps needed to take a description produced, for example, using computer-aided design (CAD) and convert it into a 3D volumetric mesh that can be used for simulation and analysis. Currently, using state-of-the-art mesh generation software takes scientists weeks or even months to generate a new computational mesh from scratch. Rapsodi is developing algorithms and tools that will help reduce this setup time to less than a day for a significant fraction of the simulation and analysis applications at Lawrence Livermore National Laboratory.

Hybrid Mixed-element Mesh Generation

The Rapsodi project is using an automated component-based mesh generation (CBM) procedure for constructing hybrid meshes that include regions of both structured and unstructured mesh. Such meshes will be useful to simulation codes that can accept general unstructured mixed-element meshes. A particularly important feature of this approach is that it is incremental. New components can be added to an existing CBM mesh without starting from scratch. The CBM approach recognizes that many complex engineering geometries are originally designed by combining simple components together into a more complex configuration. In an analogous fashion, the CBM procedure begins by constructing a structured hexahedral component mesh, or a set of structured meshes around each component, and then connecting all of these component meshes with regions of unstructured mesh, called connection meshes. Research activities for this approach are currently focused on the development of automated techniques for generating the component meshes from CAD input data, and the development of effective and appropriate algorithms for constructing the connection meshes.

The Geometry-to-Mesh Construction Process

Since geometry specifications such as CAD were not designed with mesh construction in mind, there are few standard tools for converting them to parameterizations that can readily be used by mesh generation tools. The Rapsodi project interacts with CAD descriptions through a common file format called IGES (Initial Graphics Exchange Specifications) that is supported by most common CAD packages. The representation extracted from an IGES file is a set of trimmed spline patches (NURBS) that completely cover the surface. This representation is often not "water tight" or single-valued. Converting the input geometry to a mesh-appropriate representation can therefore include repairing the CAD by filling gaps, reconciling errors in NURBS trimming curves, determining NURBS surface connectivity information,

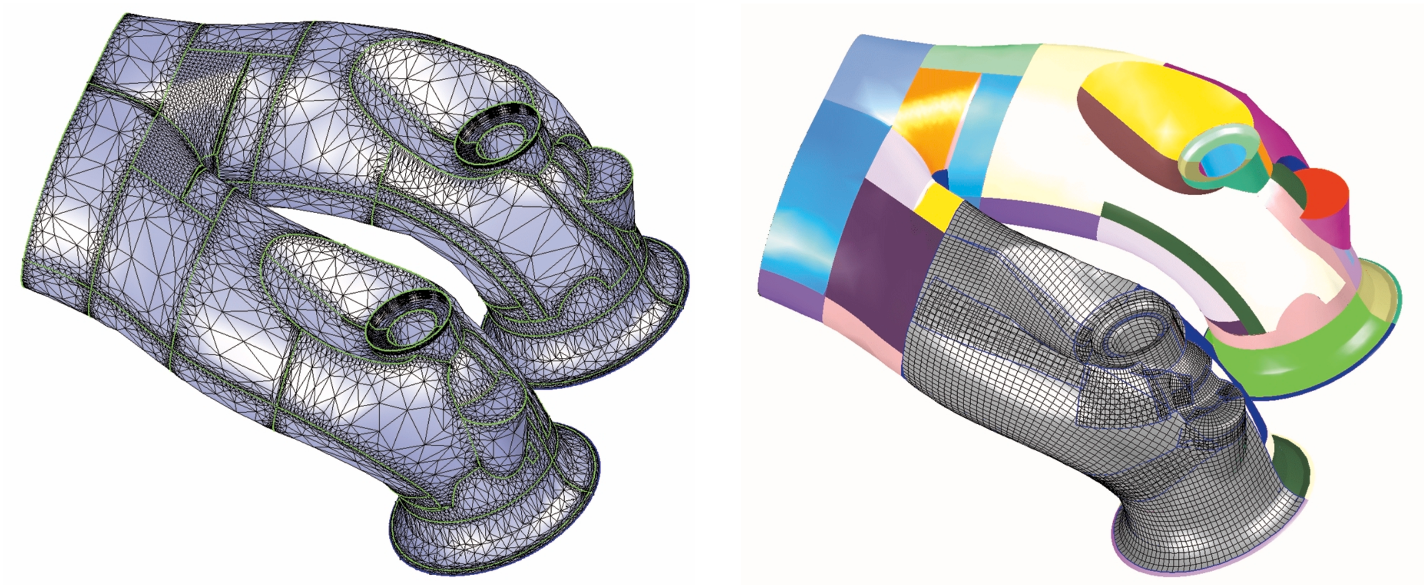

Figure 2. Two steps in the construction of a mesh from a repaired CAD description are shown here. At left, a reference triangulation is constructed on each of the patches in trimmed NURBS description of the Volvo exhaust manifold geometry. This step also determines the connectivity of the patches and reconciles overlaps and gaps between adjacent patches. The reference triangularization is used to accelerate the construction of the surface meshes (shown in gray at right), the first step in construction of a hybrid volume grid for the interior geometry.

and removing unnecessary engineering details from the specification. The RAP software tool under development in CASC allows much of this work to be done very quickly through an interactive graphics user interface.

Once the CAD geometry has been cleaned up and repaired, it can be used to generate a computational mesh. Information from the NURBS representation is used to subdivide the surface representation into components that are then individually meshed. As a practical matter, the component meshes must be generated within seconds on a typical scientific workstation; this necessitates the development of very fast algorithms for evaluating the NURBS representation. Rapsodi software automatically determines adjacency information and constructs a reference triangularization of the surface. Evaluating a point on the geometry surface can then be done much more rapidly by first locating its reference triangle and then using this to find the original location on the patched NURBS surface.

A set of surface meshes is then constructed that cover the computational geometry. This is done using a marching technique called "hyperbolic grid generation" in which a partial differential equation is solved for the coordinates of the surface mesh. From the surface meshes, volume "component meshes" are built. The overall hybrid mesh is then constructed by connecting the component meshes with regions of high-quality unstructured mesh using an advancing front technique. This results in an unstructured mesh over which the user has considerable control, and which has large regions of structure that can be exploited for accuracy and efficiency in the ultimate application code.

For additional information about Rapsodi, contact David L. Brown (925) 424-3557, dlb@llnl.gov; Bill Henshaw (925) 423-2697, henshaw@llnl.gov;or Anders Petersson (925) 424-3804, andersp@llnl.gov. Information is also available on the Web at http://www.llnl.gov/casc/rapsodi/.

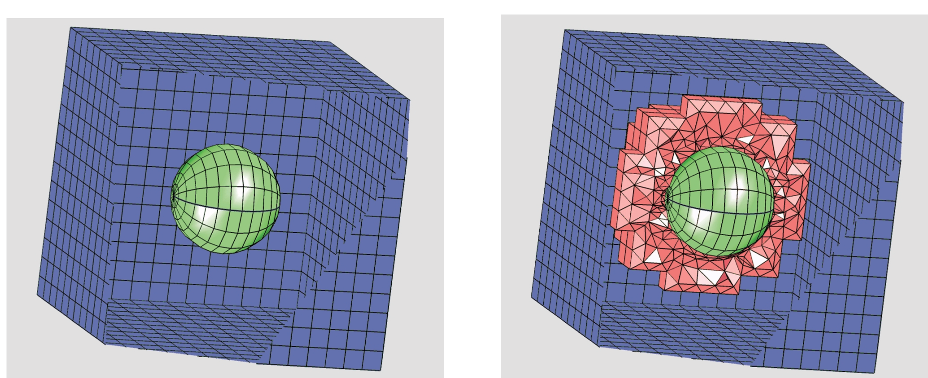

Figure 3. Rapsodi's hybrid mesh construction algorithm uses software from CASC's Overture project to cut a hole in the blue mesh that is then filled in with an unstructured mesh (shown in red at right) that connects the blue and green structured meshes.

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.